RESEARCH DEMONSTRATION OF A DECOMPOSITION APPROACH FOR LARGE-SCALE, COUPLED SURFACE-SUBSURFACE WATERSHED MODEL CALIBRATION AND VALIDATION

H-P. Cheng[1], S.M. England[2], H-C. Lin[1], J-R.C. Cheng[1], E.V. Edris[1], S.L. Ashby[1], D.R. Richards[1]
[1]U.S. Army Engineer Research and Development Centre, Vicksburg, MS, USA
[2]The Philadelphia District, U.S. Army Corps of Engineers, Philadelphia, PA, USA

Keywords: calibration, validation, decomposition approach, coupled surface-subsurface model, watershed model, GMS, WASH123D.

Numerical modelling codes and computational resources have progressed to a point where accurate and useful physics-based models can now be developed to evaluate regional watershed issues in a cost-effective manner. Effective and efficient model calibration and validation for large-scale, physics-based watershed model is thus needed. It is often more efficient to sub-divide the large scale model into smaller sub-domains for calibration and validation. This paper presents a decomposition approach for large-scale watershed model calibration and validation, where the watershed system can be conceptualized as a combination of 1-D channel networks, 2-D overland regimes, and 3-D subsurface media. This decomposition approach subdivides the whole-domain model into several sub-domain models by using existing channels as the "cut" boundary to separate sub-domains. Four steps are included in the model calibration and validation process. In step 1, the coupled 2-D/3-D sub-domain models are constructed and calibrated, where the historical 1-D channel stages are used as boundary conditions on ground surface. In step 2, the coupled 1-D/2-D/3-D sub-domain models are constructed and calibrated, where the finalized overland and subsurface model parameters from Step 1 were fixed such that only the channel model parameters are adjustable in this step. In step 3, the sub-domain models are stitched together into the whole-domain model, and the model parameters calibrated from the previous steps are fixed for the coupled 1-D/2-D/3-D whole-domain model calibration. In this step, only the channel model parameters associated with the "cut" boundary are adjustable. In Step 4, the calibrated coupled 1-D/2-D/3-D whole-domain model from the former steps is validated against a set of field data other than that used for calibration. This decomposition approach allows the modeller to conduct more model runs at the sub-domain level, rather than at the whole-domain level, which helps generate a better calibrated/validated model within the given modelling time.

In this paper, a hypothetical example is employed as a proof of concept to verify the proposed decomposition approach. This paper also describes the application of

this modelling process to a regional-scale watershed system in South Florida that covers an area over 8,000 square miles as part of a research demonstration project in the Corps of Engineers Civil Work's System-Wide Water Resources Program at US Army Engineer Research and Development Centre. (ERDC). Through the verification and the demonstration, the following points were drawn:

- The proposed decomposition approach is adequate for large-scale watershed model calibration and validation.
- The hydro-static assumption used to set up boundary conditions on the "cut" boundary for sub-domain models may introduce source error in the sub-domain model calibration.
- For a coupled surface-subsurface watershed model, daily canal stage data may be used to calibrate the subsurface flow model. However, sufficient temporal resolution of the canal structure flow rate data (e.g., hourly or every 15 minutes) is essential for calibrating canal flow models.

The US Department of Defence Groundwater Modelling System and the ERDC in-house WASH123D numerical model were used to construct and perform computer simulations, respectively. All the model runs were conducted on a PC cluster machine in ERDC's Major Shared Resource Centre for high performance computing.

Abstract

This paper proposed a decomposition approach in order to calibration and validate a large-scale, coupled surface-subsurface watershed model in an effective and efficient manner. With this approach, the entire watershed system is subdivided into several sub-domain systems with existing channels as the "cut" boundary between sub-domains. This paper uses a hypothetical example as a proof of concept to verify the decomposition approach. It also describes how the approach was applied to a watershed system in South Florida that covers an area over 8,000 square miles as part of a research demonstration project.

Keywords: calibration, validation, decomposition approach, coupled surface-subsurface model, large-scale, watershed model, South Florida.

1 Introduction

1.1 Comprehensive, Physics-Based Watershed Modelling

Surface water and groundwater are often intimately connected in a watershed system, and changes in one will affect the other over time periods and distances at various degrees. A river reach in a watershed system can be a gaining stream, a losing stream, or alternating between the two during different periods of time, depending on the local environment. The local environment, resulting from a combination of geology, hydrology, meteorology, topography, land use, and human development, varies in both space and time. As a result, the entire watershed system is usually complex and dynamic. It is thus essential to construct large-scale, comprehensive physics-based watershed models to help understand the local behaviours at specific locations within the system and/or the overall responses of the entire watershed for desired purposes [1], e.g., evaluation and comparison of project alternatives concerning water supply and distribution.

Ideally, no model calibration and validation is needed for a completely first-principle, physics-based model when all the system physics can be exactly interpreted and all model parameters can be accurately determined through parameterization [2, 3]. In reality, however, all watershed flow models are empirical to some degree because it is impossible to perfectly model every single detail of the complex natural system due to human limitations in observation, interpretation, and computational capability. As a result, it becomes an unavoidable task in most occasions to go through the model calibration and validation process to determine adequate model parameters and demonstrate their acceptability.

1.2 Modelling Challenge in Large-Scale Watershed Modelling

The main challenges for large-scale watershed modelling with physic-based models are bigness and complexity. Adequately resolving system physics, sufficient field data, effectively constructing computer models, and accurate and efficient computer solutions are four key factors for successful watershed modelling with computer simulation. As the watershed scale increases and more complexity involved, the modelling issues associated with the aforementioned four key factors become more difficult to deal with. Model calibration and validation, which is essential for locating model parameter and identifying applicable range for model application, can be lengthy and intricate as a result.

1.3 Approach for Large-Scale Model Calibration and Validation

We present in this paper a decomposition approach to help produce better calibrated/validated large-scale watershed models within the given modelling time. The following sections describe how the approach is used in conjunction with the WASH123D computer model [4] to simulate water flow in coupled surface-subsurface watershed systems. A hypothetic test example is used to verify the approach, and a large-scale South Florida watershed system is used to demonstrate how the four-step decomposition approach is executed in practice.

2 Method

2.1 WASH123D

The WASH123D model was used to demonstrate the decomposition approach for model calibration and validation. WASH123D is a finite element numerical model which computes water flow in watershed systems that can be conceptualized as a combination of one-dimensional (1-D) channel networks, two-dimensional (2-D) overland regimes, and three-dimensional (3-D) subsurface media. In the computer program of WASH123D that US Army Engineer and Development Centre maintains, 1-D channel flow is computed by solving the cross-section area-averaged diffusive wave equation (i.e., Equation (1) below), 2-D overland flow by the depth-averaged diffusive wave equation (i.e., Equation (3) below), and 3-D variably saturated subsurface flow by the Richards equation (i.e., Equation (5) below). The continuity equations of flow and/or state variables (e.g., head and water stages) are applied at surface-subsurface interface, channel-overland interface, and channel junctions where storage can be neglected. Both head- and flux-type boundary conditions can be set up based on their availability to close the computational system. The semi-Lagrangian finite element method [5, 6, 7] is applied to solve the diffusive wave equations for 1-D channel flow and 2-D overland flow, while the Galerkin finite element method [8] is used to solve the Richards equation for 3-D subsurface flow. The governing equations solved in WASH123D are described as follows.

2.1.1 1-D Diffusive Wave Equation

Equation (1) $$\frac{\partial A}{\partial t} + \frac{\partial (AV)}{\partial x} = S_S + S_R - S_E - S_I + S_1 + S_2 \,,$$

where t is time [t]; x is the axis along the channel direction [L]; A is cross-sectional area of the river/stream [L^2]; S_S is the man-induced source [L^3/L/t]; S_R is the source due to rainfall [L^3/L/t]; S_E is the sink due to evaporation [L^3/L/t]; S_I is the sink due to infiltration [L^3/L/t]; S_1 and S_2 are the source terms contributed from overland flow [L^3/L/t]; V is the cross-section-averaged flow velocity of the channel [L^3/t] and is computed in WASH123D with Equation (2) [9].

Equation (2) $$V = \frac{-a}{n1}\left[\frac{R}{1+\left(\frac{\partial z_0}{\partial x}\right)^2}\right]^{2/3} \frac{\frac{\partial H}{\partial x}}{\sqrt{\left|\frac{\partial H}{\partial x}\right|}} \,,$$

in which, $n1$ is Manning's roughness coefficient [t/$L^{1/3}$]; a is a unit-dependent factor (a = 1 for SI units and a = 1.49 for U.S. customary units) to make the Manning's roughness coefficient unit-independent; z_0 is channel bottom elevation [L]; R is hydraulic radius [L]; and H is the water stage [L].

2.1.2 2-D Diffusive Wave Equation

Equation (3) $$\frac{\partial h}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial\,(vh)}{\partial y} = S + R - E - I \,,$$

where h is water depth [L]; u is the velocity component in the x-direction [L/t]; v is the velocity component in the y-velocity [L/t]; S is the man-induced source [L^3/L^2/t]; R is the source due to rainfall [L^3/L^2/t]; E is the sink due to evapo-transpiration [L^3/L^2/t]; and I is the sink due to infiltration [L/t]. It should be noted that $uh = q_x$ is the flux in the x-direction [L^3/L/t] and $vh = q_y$ is the flux in the y-direction [L^3/L/t]. The depth-averaged overland flow velocity is calculated in WASH123D with Equation (4) as follows [9]:

Equation (4) $\mathbf{V} = \dfrac{-a}{n2}\left[\dfrac{h}{1+(\nabla z_0)^2}\right]^{2/3}\dfrac{\nabla H}{\sqrt{|\nabla H|}}$,

in which, $n2$ is Manning's roughness coefficient [t/L$^{1/3}$]; a is a unit-dependent factor to make the Manning's roughness coefficient unit-independent; z_0 is channel bottom elevation [L]; H is the water stage [L]; and ∇ is the del operator.

2.1.3 3-D Richards Equation

Equation (5) $\left(\alpha'\dfrac{\theta_e}{n_e}+\beta'\theta_e+n_e\dfrac{dS}{dh}\right)\dfrac{\partial h}{\partial t}=\nabla\cdot\left[k_r\mathbf{K_s}\cdot(\nabla h+\nabla z)\right]+q$,

where α' is the modified compressibility of the medium [1/L]; θ_e is the effective moisture content [L^3/L^3]; n_e is the effectively porosity [L^3/L^3]; β' is the modified compressibility of water [1/L]; and S is the degree of saturation [dimensionless]; h is the pressure head [L]; t is the time [t]; k_r is the relative hydraulic conductivity [dimensionless]; $\mathbf{K_s}$ is the saturated hydraulic conductivity tensor [L/t]; z is the potential head [L]; q is the source/sink term [L^3/L^3/t]. The Darcy's velocity is given by Equation (6).

Equation (6) $\mathbf{V}=-k_r\mathbf{K_s}\cdot(\nabla h+\nabla z)$

2.2. The Four-Step Decomposition approach

The model parameters employed in WASH123D for coupled surface-subsurface flow simulation include at least Manning's roughness coefficients for 1-D channel flow (i.e., $n1$ in Equation (2)), Manning's roughness coefficients for 2-D overland flow (i.e., $n2$ in Equation (4)), and saturated hydraulic conductivities for 3-D subsurface flow (i.e., $\mathbf{K_s}$ in Equation (6)). For a large-scale watershed system that contains complex geological heterogeneity, various land use, and different channel characteristics, the model parameters to be calibrated and validated can be many. We propose a decomposition approach for effective and efficient model calibration and validation when the modelling system is large. This approach uses some existing channels as the "cut" boundary to separate one sub-domain from another, which gives us the privilege to use the historical channel stage data to set up boundary conditions for the sub-domain models in the following four-step iteration process:

<u>Step 1</u>. Construct and calibrate the coupled 2-D/3-D sub-domain models, where the historical channel stage data is used to set the head-type boundary condition on (1) ground surface nodes corresponding to channels and (2) the side boundary face associated with the "cut" boundary.

<u>Step 2</u>. Construct and calibrate the coupled 1-D/2-D/3-D sub-domain models, where the overland and subsurface model parameters finalized from Step

1 are fixed such that only the flow model parameters associated with channels included in the sub-domain models are adjustable in this step. Here the historical channel stage data associated with the "cut" boundary is still used to set the head-type boundary condition on the side boundary face associated with the "cut" boundary.

Step 3. Construct the coupled 1-D/2-D/3-D whole-domain model by stitching sub-domain models together into the whole-domain domain; calibrate the model to find adequate flow parameter values for the channels representing the "cut" boundary, where the model parameters finalized from the previous two steps are fixed in this step.

Step 4. Validate the coupled 1-D/2-D/3-D whole-domain model using the final parameters values used for Step 3.

It is noted that each of the four steps may require multiple model runs before reaching a satisfactory result. Iterations between the four steps are also necessary for model improvement during the course of calibration and validation. Although this approach, like the other calibration-validation procedures, will still need an iterative process to reach satisfactory results, it has the following advantages for better outcomes:

- Most model runs will be conducted at the sub-domain level instead of at the whole-domain level, which allows more model runs within the given period of time for modelling. As a result, better calibration can be expected.
- Model calibration at the sub-domain level can be conducted in parallel for all sub-domain models to save time.
- It is more effectual to adjust fewer model parameter in each of the first three steps than to calibrate the coupled channel, overland, and subsurface flow model in one time.
- It will require lesser effort and time to refine sub-domains than the whole domain when necessary.

3. Verification of the Decomposition approach

3.1. The Hypothetical Test Example

A hypothetical test example was used to verify the decomposition approach. Figure 1 shows the topographic colour contour and the canal network system of the test example. The coupled 1-D/2-D/3-D whole-domain model was constructed with 117 nodes and 104 line elements for 1-D canal, 1,882 nodes and 3,610 triangular elements for 2-D overland, and 20,702 nodes and 36,100 triangular prism elements for 3-D subsurface flow computation. It was horizontally sub-divided into three sub-domains: SD-1, SD-2, and SD-3, as shown in Figure 2. Canal reaches 1, 3, 4, 8, and 11 (Figure 1) served as the "cut" boundary between sub-domains. The red, blue and green crosses in Figures 1 and 2 are where we will show comparison of canal stage, overland water depth, and subsurface total head from the whole-domain and the sub-domain models. They are labelled with different letters.

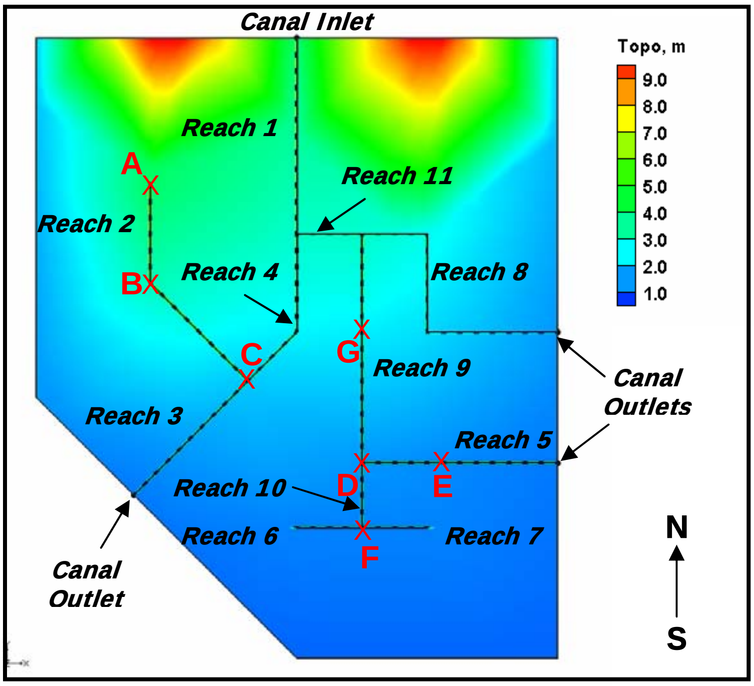

Figure 1: Canal network, topographic colour contour, and seven verification locations of canal water stage for the hypothetical test example.

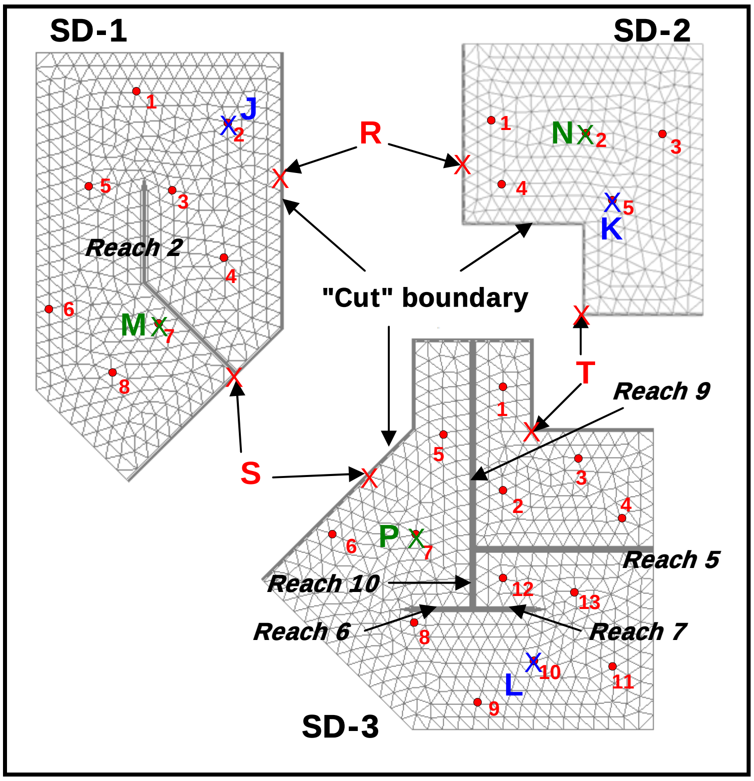

Figure 2: The three sub-domains, canal reaches, and verification locations of overland water depth and ground water head for the hypothetical test example.

This hypothetical test example was designed to represent a general watershed system. The following features were included in the test example, as more detailed description about the whole-domain model can be found elsewhere [10]:

- Heterogeneity in 1-D canal, 2-D overland, and 3-D subsurface.
- Surface-subsurface interaction through infiltration and seepage.
- Variable rainfall both spatially and temporally.
- Triggered groundwater pumping to canal.
- Head-type and flux-type boundary conditions for both surface and subsurface flow computation.
- Multi-frame approach for coupled simulation: the time step sizes for the computation of 1-D canal flow, 2-D overland flow, and 3-D subsurface flow were 0.5 sec, 5 sec, and 30 min, respectively.

These features were incorporated when the whole-domain and the sub-domain models were constructed through the WASH123D graphical user interface in the US Department of Defence Groundwater Modelling System (GMS, http://chl.erdc.usace.army.mil/gms). The whole-domain model and the sub-domain models had consistent set-up except (1) the canals associated with the "cut" boundary were not considered for computation in the sub-domain models, and (2) the canal stage result from the whole-domain model was used to set up boundary conditions along the "cut" boundary for the sub-domain models.

To verify the proposed decomposition approach is valid, agreement must exist in the following model solutions:

- Canal stage solutions from the whole-domain and the sub-domain models.
- Overland water depth from the whole-domain and the sub-domain models.
- Groundwater head from the whole-domain and the sub-domain models.
- Overland water depth from the coupled 2-D/3-D and the coupled 1-D/2-D/3-D models at both the whole-domain and the sub-domain levels.
- Groundwater total head from the coupled 2-D/3-D and the coupled 1-D/2-D/3-D models at both the whole-domain and the sub-domain levels.

By using strict stopping criteria (the maximum absolute error of 10^{-4} m, 10^{-4} m, and 10^{-3} m was used in this study for 1-D, 2-D, and 3-D computation, respectively) and sufficient resolution on the spatial and temporal discretization in numerical computation, we took the result from the coupled 1-D/2-D/3-D whole-domain model run to represent the field data of the watershed system in the hypothetic test example. Based on the hourly canal stage solution from this whole-domain model run, we constructed (1) the coupled 2-D/3-D whole-domain model, (2) the coupled 1-D/2-D/3-D sub-domain models, and (3) the coupled 2-D/3-D sub-domain models. In the next section, we examine whether or not the solutions from these models agree with one another.

3.2 Model Run Results and Analysis

Comparison of computational results from the coupled 1-D/2-D/3-D model and its corresponding 2-D/3-D model demonstrates excellent agreement in both overland water depth and groundwater total head at the whole-domain as well as the sub-domain levels though it is not shown here. This indicates using 1-D canal stage to set up boundary conditions on ground surface for coupled 2-D/3-D model calibration is adequate.

3.2.1 Comparison of Canal Stage Solutions

Excellent agreement was found when we compared water stage and flow rate at seven locations in the canal system between the whole-domain run and the sub-domain runs (i.e., Run 1 vs. Runs 3-4) in Figure 3. These locations are marked in Figure 1, where three of them were in SD-1 (i.e., A to C) and the others SD-3 (D to G).

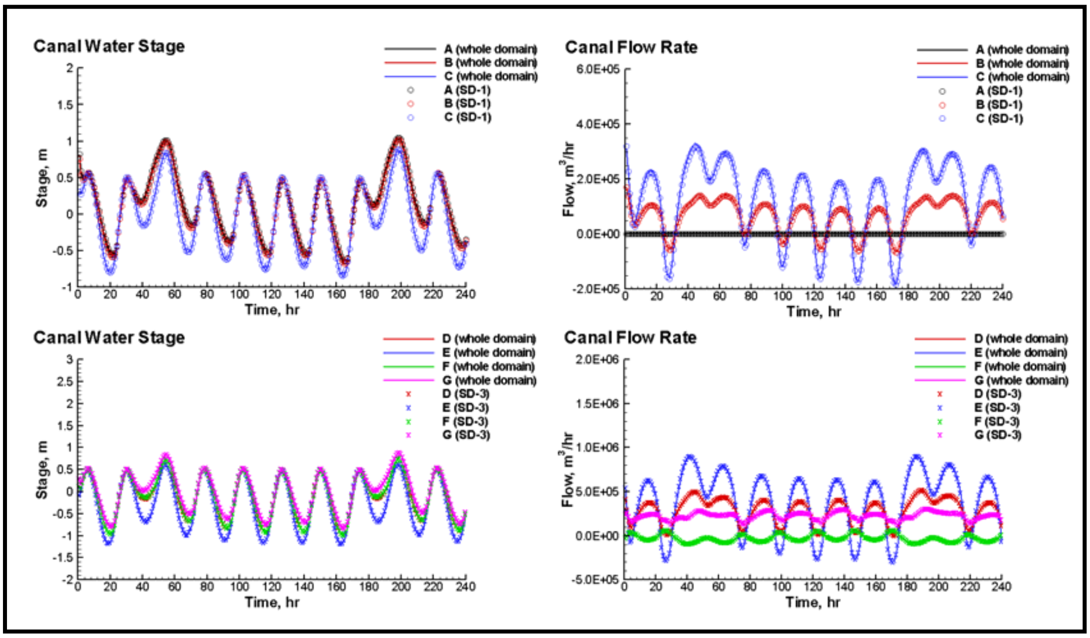

Figure 3: Comparison of canal water stage (left plots) and flow rate (right plots) at seven locations from the whole-domain and sub-domain model runs.

3.2.2 Comparison of Groundwater Total Head

Figure 4 compares the computed groundwater head from the whole-domain model and the sub-domain models (i.e., Run 2 vs. Runs 5-7) at three locations: M in SD-1, N in SD-2, and P in SD-3 (Figure 2). The total head values were extracted from mesh nodes that were 2 ft below ground surface. A close examination confirmed that the total head differences were mainly caused by the application of the hydro-static assumption in setting up the head type boundary condition along the “cut” boundary for sub-domains. The farther the comparison location was from the “cut” boundary, the smaller the head difference was observed.

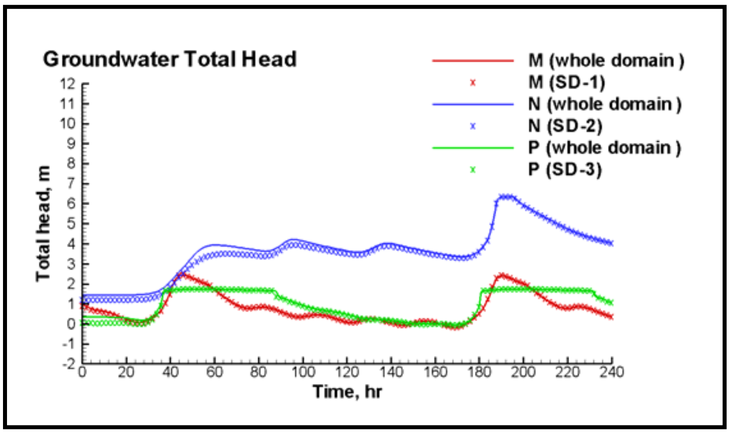

Figure 4: Comparison of groundwater total head at three locations from the whole-domain and sub-domain model runs.

To demonstrate how the application of the hydro-static assumption to the "cut" boundary would affect the sub-domain result, the computed total head values at various depths below the canal bottom were compared in Figure 5 at three locations on the "cut" boundary (R, S, and T in Figure 2). The periodic cycles reflects the tidal effect from the downstream canal outlets. It is obvious from Figure 5 that the hydrostatic assumption can be considered reasonable for most of the 240-hr simulation period. However, it is also revealed that the hydrostatic assumption introduced a greater error to the "cut" boundary condition during rainfall periods than non-rainfall periods. It is because the rainfall effect on groundwater head decreases with the depth, and the water moves much faster in canals than in the subsurface system. Therefore, we must be aware of this boundary condition effect in calibrating the sub-domain models.

3.2.3 Comparison of Overland Water Depth

Comparison of overland water depth from the whole-model run and the sub-domain model runs was made at 8 locations in SD-1, 5 locations in SD-2, and 13 locations in SD-3. High agreement was found at most of these locations, while slight differences were observed at some locations as demonstrated in Figure 6. In Figure 6, comparison of overland water depth at three locations (J in SD-1, K in SD-2, and L in SD-3, Figure 2) was plotted. The differences were caused mainly due to two things. First, the error associated with the hydro-static assumption on the "cut" boundary made some differences in the subsurface flow between the whole-domain and sub-domain models, as mentioned in Section 3.2.2. Second, the substantial overland-subsurface interaction through infiltration and seepage in this test example passed the impact of the hydro-static assumption on subsurface flow to overland water depth. It is noted that the much faster flow dynamic in canals is the reason why this hydro-static assumption impact on canal flow was minimal in this test example (Figure 3).

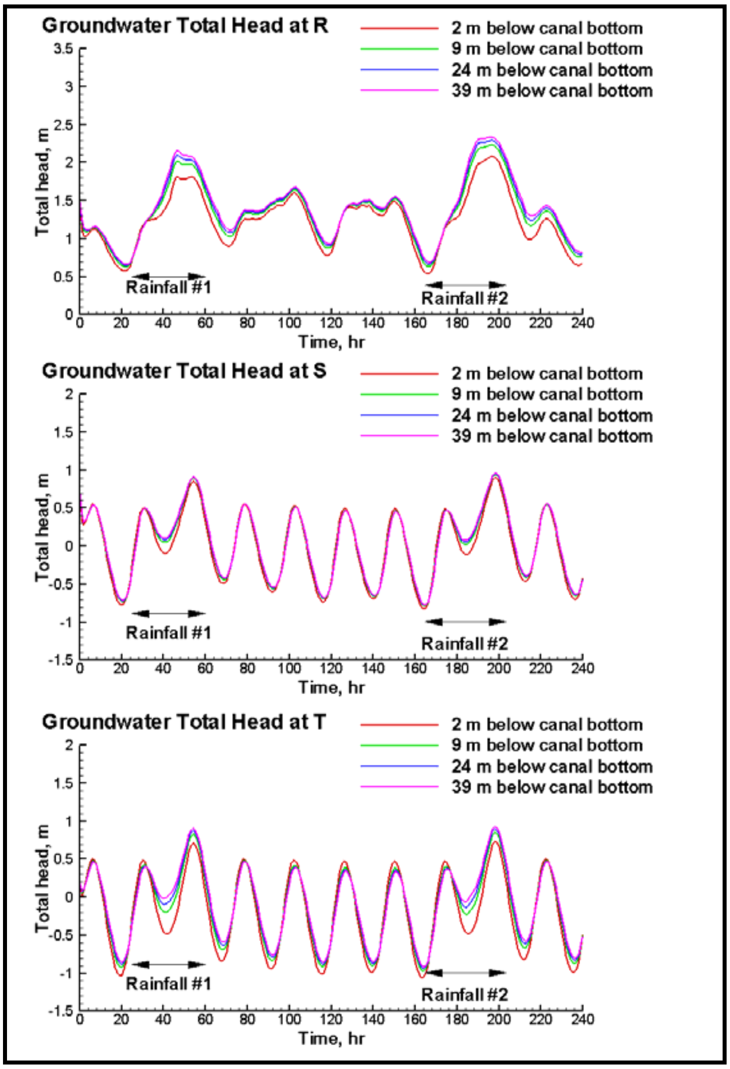

Figure 5: Comparison of groundwater total head at various depths below canal bottom at R, S, and T, which are on the "cut" boundary of the test example.

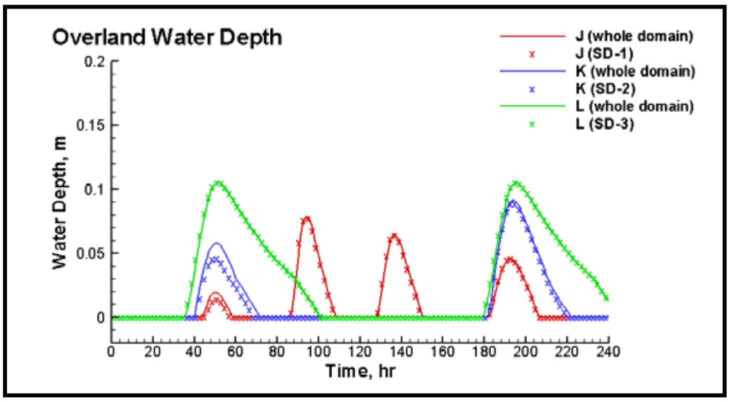

Figure 6: Comparison of overland water depth at three locations from the whole-domain and sub-domain model runs.

4 Demonstration of Large-Scale Watershed Model Calibration

We used a hypothetical test example in Section 3 to show the proposed decomposition approach is useful for model calibration and validation. In this section, we demonstrate how the decomposition approach was implemented for calibrating a regional South Florida watershed model. Because this application was for a demonstration purpose, only the available compiled field data made available to use at the time of this 6-month long project was incorporated into the model, and the model to be demonstrated below must not be considered well calibrated. Moreover, some needs for constructing a physics-based regional watershed model were revealed during this demonstration effort.

4.1 Background Information of South Florida Regional Model

For this research demonstration model, an approximately 8,000 square mile area of South Florida from just north of Lake Okeechobee to the southern tip of the Florida Peninsula was selected. The lateral extents of this model are shown in Figure 7, which covers most project domains considered in the Comprehensive Everglades Restoration Plan (CERP, http://www.evergladesplan.org/index.aspx). The whole-domain model was subdivided into five sub-domains (SD-1 through SD-5, Figure 8), where SD-2 represents Lake Okeechobee and the lake stage data was used to set up boundary conditions for the connecting sub-domains (i.e., SD-1, SD-3, and SD-4). These sub-domains were separated by selected canals: the L-8 and the West Palm Beach canals were the "cut" boundary between SD-1 and SD-4; the L-29, the L-24, the L-23, the C-123, the C-304, and the L-30 canals between SD-3 and SD-4; the Tamiami and the L29 canals between SD-3 and SD-5; and the C-4 canal between SD-4 and SD-5. The "cut" boundary is represented with white lines in Figure 8. Each of these sub-domains was first calibrated individually. The hydraulic parameters from each of the calibrated sub-domain models were then used for the whole-domain model calibration according to the four-step decomposition approach.

4.2 Construction of Regional Model

4.2.1 Field Data

The field data compiled and used to construct the South Florida regional model included the following:

- Topography based on the South Florida Digital Elevation Model Report.
- Land use information based on which the types of overland roughness were defined.
- Hydro-geology based on borehole data.
- Canal network system that contained major canals and structures.
- Canal cross-sectional geometry data.

- Daily rainfall and evapo-transpiration (ET) data.
- Daily canal water stages and structure flow rates.
- Daily overland water stages.
- Daily groundwater heads.

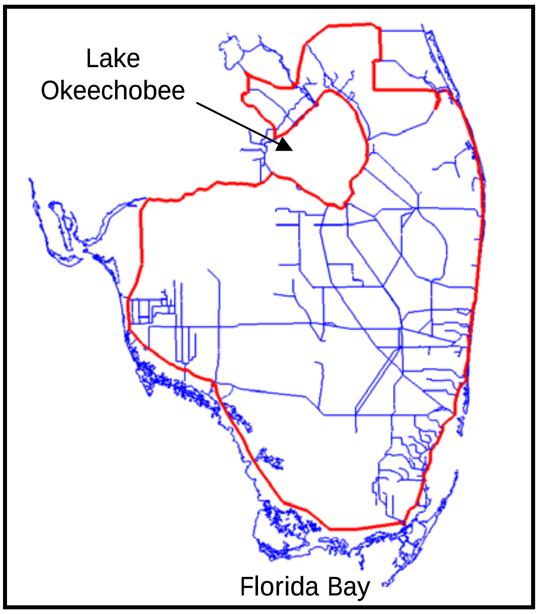

Figure 7: Lateral extents of the South Florida regional model for research demonstration.

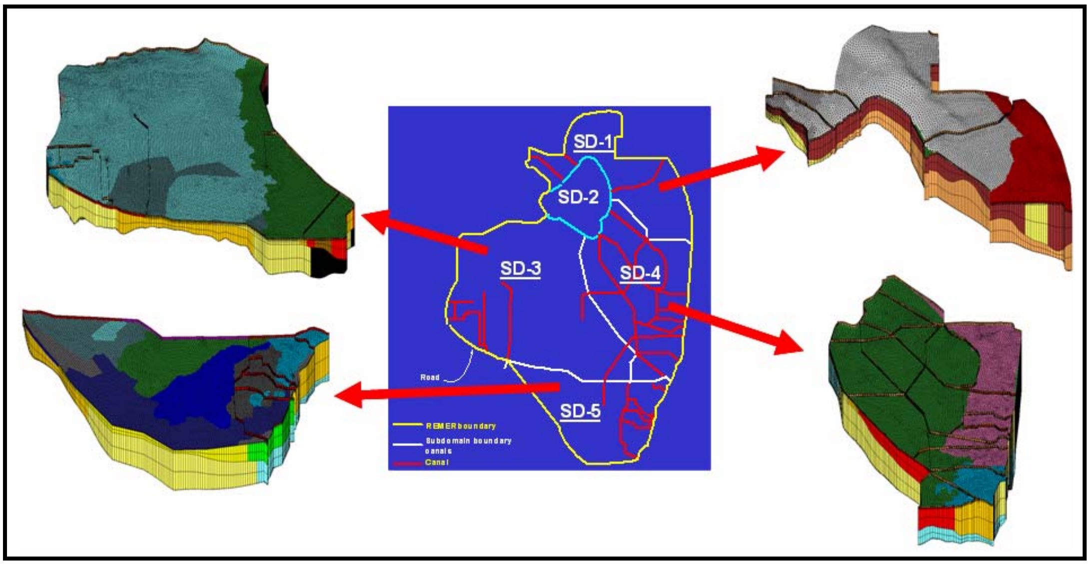

Figure 8: Sub-domains considered the South Florida regional model for demonstration: different colours represent different subsurface materials.

A set of simplified curves were used to describe the unsaturated soil characteristics due to the lack of field data. No surface or subsurface pumping was incorporated into the model because the data was not available.

The horizontal datum used for this model was NAD83, State Plane Florida East. The vertical datum used was NAVD88 (North American Vertical Datum 1988) datum. All data sets were converted to this common horizontal and vertical datum using the coordinate conversion software, Corpscon 6.0 (http://crunch.tec.army.mil/software/corpscon/corpscon.html), developed by the Topographic Engineering Centre of the U.S. Army Corps of Engineers.

4.2.2 Computational Meshes

GMS was used to construct computational meshes and set up WASH123D model runs at both the sub-domain and the whole-domain levels based on the compiled field data. Table 1 lists the mesh information (numbers of node and element) for the whole-domain and the sub-domain models.

	1-D Canal		2-D Overland		3-D Subsurface	
Model	No. of Node	No. of Element	No. of Node	No. of Element	No. of Node	No. of Element
Whole-Domain	1,741	1,615	45,997	90,903	321,979	545,481
SD-1	179	165	7,267	14,045	50,869	84,270
SD-3	206	197	16,561	32,637	115,927	195,822
SD-4	792	471	13,515	26,577	94,605	159,462
SD-5	214	186	8,490	16,592	59,430	99,552

Table 1: Mesh information of the whole-domain and sub-domain models for the South Florida regional model.

4.2.3 Boundary Conditions

All side boundary nodes in the 3-D mesh were assigned total head boundary conditions based on observed transient data. The hydrostatic assumption was applied on the side boundary when the observed transient data was not available at different depths below ground surface. GMS linearly interpolated between the observed data points along the boundary.

The daily rainfall and ET data were employed to set the boundary condition for the top face of the coupled surface-subsurface model.

In the coupled 2-D/3-D model, at both whole-domain and sub-domain levels, the observed stages of the interior canals were employed as boundary conditions. In order to replicate the effect of variations of canal stage in the 2-D/3-D models, the observed canal stages were assigned as enforced total head boundary conditions on ground surface for 3-D subsurface computation and specified stage boundary conditions for 2-D overland computation.

A zero-depth type boundary condition was applied where overland drainage divides were represented. These overland drainage divides may be on the domain boundary or present within the model domain. A specified-stage or specified-flux type boundary condition was used where surface flow can pass over the domain boundary, either inward or outward.

The flow rate recorded at a canal structure was used to set up boundary conditions for its upstream and downstream canals in model calibration and validation.

4.3 Model Calibration and Validation

For this calibration and validation effort, two- four month long simulations were used. A wet season (May 2000-August 2000) was used for calibration and a dry season (January 2001-April 2001) was used for validation.

As described in the decomposition approach, the calibration and validation of this regional model was performed in stages. The sub-domain models were first developed and calibrated in steps 1 and 2. The model parameters from these calibrated sub-domain models were then used to perform the final calibration and validation of the whole-domain model in steps 3 and 4. The model was calibrated by adjustments to model parameters, including hydraulic conductivity and Manning's roughness to match the computed head and stages with the observed field data at gages throughout the study area.

4.3.1 Sub-domain Model Calibration Results

To illustrate the procedure, the calibration of SD-5 is presented. SD-5 is located in the southern portion of the regional model (Figure 8). The northern boundary that is also the "cut" boundary of SD-5 is along the Tamiami Canal, L-29, and C-4 Canal. The eastern boundary extends along the Atlantic coast from the Miami canal to the downstream of S197 structure located in C-111 canal. The boundary then follows a series of groundwater gages across the western and southern parts of Everglades National Park.

Within the SD-5 model domain 25 groundwater, 44 overland stage, and 17 canal stage gages were identified as having sufficient data to use for model calibration and validation, as shown in Figure 9. Figure 10 depicts the comparison of groundwater head at four locations (A, B, C, and D in the left plot of Figure 9), when calibration of the coupled 2-D/3-D model was concluded because the general trends were matched and more refining was not warranted for the demonstration. Figure 11 plots the comparison of canal water stage at three locations (F, G, and H in the right plot of Figure 9), where the computed results from the coupled 1-D/2-D/3-D model are shown.

From Figure 10, the computed groundwater head and the observed have a similar pattern at each of the four groundwater gages. This suggests that the SD-5 model may have been calibrated to a degree at which the general trend of groundwater head is adequately modelled.

The poor match in canal stage in Figure 11 indicates that using daily stage and structure flow rate to set up boundary conditions for computing canal routing was insufficient for resolving the highly dynamic canal flow. It is essential to use hourly or even minutely canal stage and structure flow rate data for canal flow calibration.

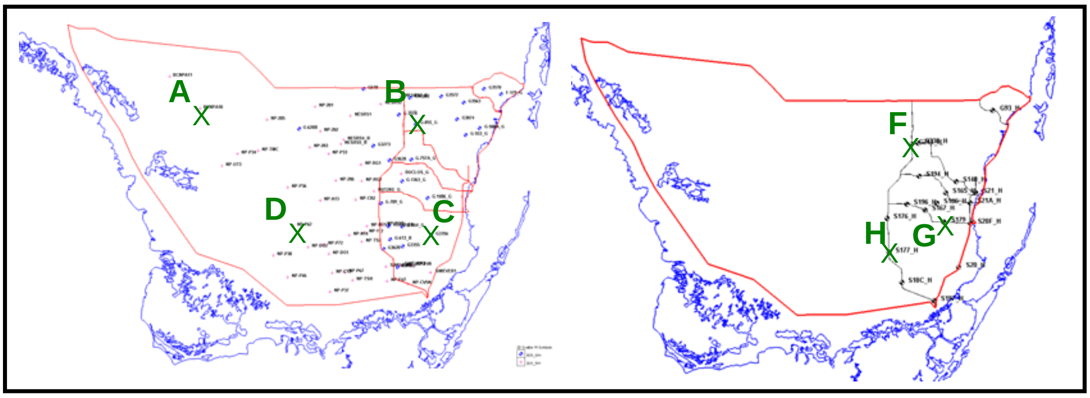

Figure 9: Observation gages used for the SD-5 Calibration: 69 overland and groundwater gages (left) and 17 canal gages (right).

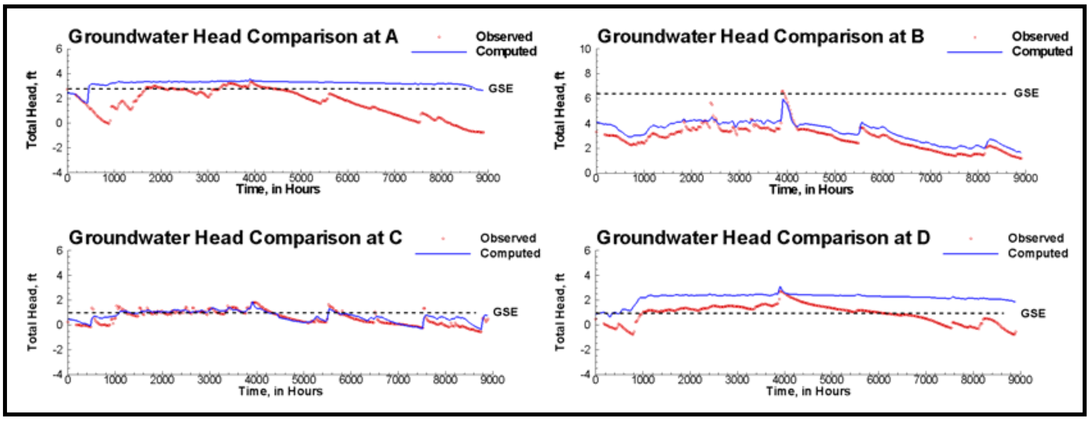

Figure 10: Groundwater head comparison at four gage locations in SD-5: the observed data is represented with red circles and the computed blue lines; GSE denotes ground surface elevation.

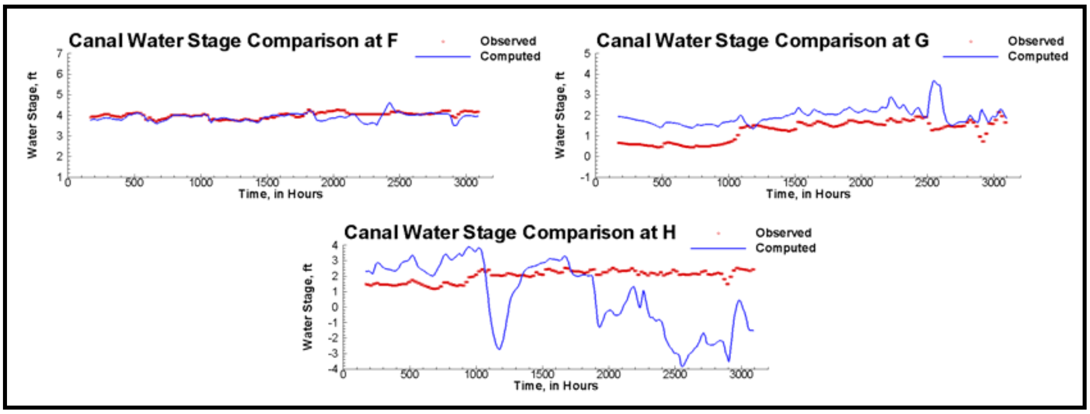

Figure 11: Canal stage comparison at three gage locations in SD-5: the observed data is represented with red circles and the computed results blue lines.

Using daily canal stage data to set up the enforced head boundary condition on the ground surface for calibrating the coupled 2-D/3-D model seemed to be acceptable. This is probably because the impact of canal water stage on groundwater head is limited to a certain distance from the canal. For example, the differences between the computed groundwater head and the observed were greater at B because the groundwater gage at B is closer to a canal when compare with the gages at the other three locations.

Similar calibration results were observed in other sub-domain models.

4.3.2 Whole-domain Model Calibration Results

Because the coupled 1-D/2-D/3-D model cannot be calibrated well with the observed daily canal stage and structure flow rate data, we analyze only the coupled 2-D/3-D model result in this section. Overall, the computed results from the whole-domain model were consistent with the corresponding results from the sub-domain models. The greatest variation is seen in areas located near the “cut” boundary that separates the sub-domain models. Figure 12 locates four gage locations for groundwater head comparison between the whole-domain and sub-domain models, where P is in SD-3, M SD-4, and R and Q SD-5. These gages were selected here because they are close to the “cut” boundary.

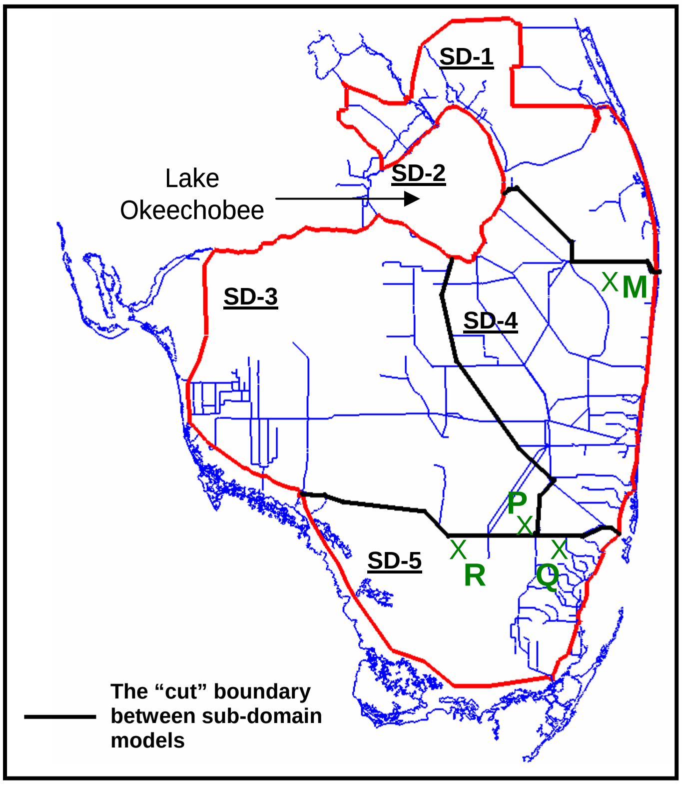

Figure 12: Four gage locations selected for groundwater head comparison between the whole-domain and sub-domain models.

Figure 12 compares the groundwater total head at the four gage locations. Although the computed results may not match the observed data well (i.e., calibration has not reached a satisfactory level, the whole-domain and the sub-domain models provided consistent results. The differences between the whole-domain model result and the sub-domain model result at a gage location was caused by the effect of boundary condition when the hydro-static assumption is applied to the "cut" boundary, as addressed in Section 3.2.2. Consequently, additional calibration of the whole-domain model may be required, once each sub-domain is calibrated. In order to reduce potential duplication of effort, it is recommended that the whole-domain model calibration begins once a reasonable calibration of the sub-domain models is achieved.

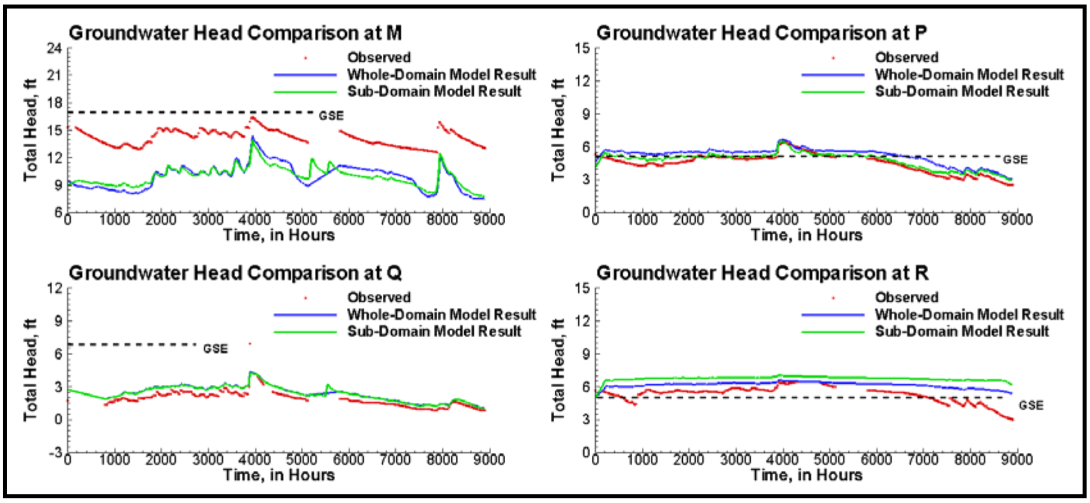

Figure 12: Groundwater head comparison at six gage locations: the observed data is represented with red circles, the computed results from sub-domain models blue lines, and the computed results from the whole-domain model green lines; GSE denotes ground surface elevation.

5 Conclusions

A four-step decomposition approach was developed to help effectively and efficiently achieve large-scale watershed model calibration and validation. A hypothetical test example was employed to prove the decomposition approach is valid provided there is sufficient spatial and temporal resolution on the field data to construct the model and numerical discretization for computer solution. A large-scale South Florida watershed system was used to demonstrate how the decomposition approach is executed in practice. The GMS modelling software and the WASH123D numerical model were used to construct model runs and compute coupled surface-subsurface flow at the whole-domain and the sub-domain levels. The main conclusions drawn from this study include:

- The proposed decomposition approach is adequate for large-scale watershed model calibration and validation.
- The hydro-static assumption used to set up boundary conditions on the "cut" boundary for sub-domain models may introduce source error in the sub-domain model calibration.
- For a coupled surface-subsurface watershed model, daily canal stage data may be used to calibrate the subsurface flow model. However, it is essential to use the canal structure flow rate data with sufficient temporal resolution (e.g., hourly or every 15 minutes) to calibrate canal flow models.

The continuation of this study may include the refinement of the decomposition approach such as:

(1) When two adjacent sub-domain models are calibrated, stitch them together and calibrate the canal flow associated with the "cut" boundary between these sub-domain models, while other sub-domains may be still under calibration.

(2) Generalize the approach such that the "cut" boundary is not limited to channels.

6. Acknowledgements

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